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MOORING MOTION WORKSHOP SUMMARY REPORT.(U)
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ABSTRACT

This report is a summary of presentations and discussions related to mooring motion problems. The workshop was conducted July 28-30, 1981. Each participant was invited on the basis of his or her expertise in mooring motion and/or upper ocean measurement. Mooring motion, as it applies to upper ocean measurement, is a highly specialized field but may be further subdivided. As each participant had interests in one or more of those subdivisions, it was natural that their presentations should reflect those interests. On the other hand, it was the responsibility of the conveners of this workshop to present the results in a format consistent with the needs and requirements of the workshop's sponsors. It is the authors' intent to present an accurate and objective view of the discussions, presentations, and recommendations that is consistent with the needs of the Ocean Measurements Program.

MOORING MOTION WORKSHOP SUMMARY REPORT

I. INTRODUCTION

The impetus for this workshop was the necessity for obtaining background environmental measurements in the upper ocean. The Physical Oceanography Branch of the Naval Ocean Research and Development Activity (NORDA) has been tasked with developing measurement systems that can be used in routine surveys designed to characterize the upper ocean physical environmental background in various geographical regions of interest to the Navy.

The upper ocean (i.e., the region from the surface to a short distance below the mixed layer) is a particularly hostile region in which to conduct physical oceanographic measurements. At the time of the workshop, only two successful experiments had obtained useful data from the upper ocean region, utilizing current meter moorings for periods of the order of one month. These were the Joint Air-Sea INteraction experiment (JASIN) which took place in the North Atlantic Ocean and the MIxed Layer Experiment (MILE) in the Pacific Ocean. Both of these experiments have shown that a significant amount of contamination, or noise, resulted from mooring motion under certain circumstances, while in others, it was possible to obtain near surface measurements of reasonable quality.

The ATOM experiment, or Acoustically Tracked Oceanographic Mooring, was designed to determine how mooring motion affects measurements in the vicinity of the maximum of the Brunt-Väisälä frequency profile. In particular, the experiment was designed to study the effects of mooring motion on current measurements in the frequency band from about 0.01 cph up to 30 cph and over length scales between 7 and several hundred meters in the vertical. This was the first in a series of experiments, the ultimate purpose being the design of routine environmental survey methods that characterize the upper ocean background. This may be thought of as the background internal wave field in the upper ocean, although internal waves are not the only processes that contribute to high-frequency variability.

The ATOM array consisted of a single point mooring, instrumented to measure the mooring motion. Translational motion of the mooring was tracked via acoustic Doppler and pulse tracking at two positions on the upper part of the mooring. The depth of the mooring was monitored by four temperature-pressure recorders and the orientation determined by three force vector recorders (see Saunders et al., 1980, and Saunders and Green, 1981, for details). The absolute value of the tension at one point in the mooring was designed to have been measured by one force-vector recorder. Eight vector averaging current meters and 13 acoustic current meters were used to obtain current data that was to be used as input to a mooring motion model. The accuracy of the model would be verified by comparing its results with the observed mooring motion derived from records of acoustic tracking and pressure. The current and temperature measuring instruments on the mooring were to be used to verify several hypotheses about the high frequency variability and forcing.

The results of these observations furnished a basis for characterizing the statistics of the background field, and contained records of anomalous events. The experience gained during the ATOM '79 experiment is being used in an advanced system design using the latest sensors and is to be placed in different geographic environments. It is possible that the next experiment will be conducted in the North Pacific Ocean in 1983 or 1984.

A major goal of this workshop was to present the ATOM tracking experiment results for information and discussions among other workers in this field, and to stimulate discussion concerning the general problem of mooring motion and the problem of measuring currents, temperatures, and other physical parameters in the upper ocean by means of long-term oceanographic moorings. This concept evolved into a more general forum for knowledgeable workers to present experiences and ideas concerning the mooring motion problem.

The basic topic areas to be considered were:

(1) mooring dynamics, including models and theory;

(2) the general problem of signal contamination due to mooring motion and its interaction with sensor response;

(3) methods for characterization and measurement of mooring motion; and

(4) methods for reducing the contamination of oceanic signals by the mooring motions.

The general philosophy was to invite, from various institutions, investigators who were knowledgeable in the field of mooring motion and signal contamination resulting from mooring motion. To foster free and lively discussion, participants were informed that this report would not contain direct references.

The discussion phase took place the first two days and a brainstorming session was held the morning of the final day to encourage the presentation of new and radical ideas for measuring upper ocean physical parameters. This was followed by a general discussion of ideas presented and a list of recommendations.

The main body of this report is a summary of the presentations. In order to foster free discussion, one condition was that no direct attribution would be made. The summary is followed by a description of the basic problem areas to be expected when making measurements in the upper ocean from moored arrays. This is a set of specific recommendations. The last section is a list of the participants and a bibliography.

II. SUMMARY OF THE PRESENTATIONS

ATOM '79 RESULTS

Most of the instruments used to characterize the mooring motion of the ATOM mooring worked reasonably well, although there were several mechanical problems. Of the three Force Vector Recorders (FVR), two failed immediately and the third appeared to fail shortly after implantation. The short segment returned from the one FVR that appeared to work was inconsistent with any other measurement made on the mooring; therefore, it is probable that that FVR did not work. The acoustic tracking instruments worked for a shorter period than planned due to a mechanical malfunction. Further, one of the channels on the pulsed acoustic tracking system failed to return useful data because one of the underwater transponders failed.

The Doppler tracking instrumentation appeared to work correctly, although there is some question regarding the response of those instruments to high frequency displacements.

The four temperature-pressure recorders worked throughout the entire period of the mooring, but some data was lost when the mooring went below the lower pressure setting of the instrument. The pulsed acoustic tracking data were taken once every 30 minutes. From these positions, velocities at a point on the mooring were computed. The mean velocity for the period under consideration was about 0.28 cm/sec with a standard deviation of about 0.3 cm/sec. This may be compared to a typical current record which had a mean of 45 cm/sec and a standard deviation of 8 cm/sec. Both the low frequency pulsed acoustic and relatively low frequency Doppler data showed the same spectral decay as the currents, namely a fall-off of about f^{-2}. At a frequency of 4 cph, the Doppler data showed a distinct flattening. It appears that this is an instrumental artifact. For most of the frequency range, the spectrum of the mooring motion was about two orders of magnitude less than that of the observed currents.

A linear regression was made between the temperature and pressure data. The purpose was to obtain a linear fit by which the depth of the mooring could be estimated from the temperatures observed on the acoustic current meter located nearest to the temperature pressure recorders in question. The correlation coefficient obtained was -0.97. From the pressure and temperature data, it was estimated that the vertical excursion of the current meter mooring was on the order of 400 to 500 meters.

In the design of the acoustic current meters the direction of the case, with respect to magnetic north, is recorded every 8 minutes. This provides a measure of the torsional motion of the mooring. It was found that over relatively long time segments the variation and angle changed slowly, separated by occasional rapid and large changes of angle of the mooring. This sporadic activity was surmised to be the result of "stick-slip" torsional motion that can be expected from swivels at high tension. Horizontal response data from the measurements of Saunders (1980) were used to correct several segments of the record. It was found that corrections on the order of about 1 cm/sec were observed. The order of magnitude of this correction is somewhat larger than that of the direct translational mooring motion.

The major results of the ATOM tracking experiment may be summarized:

(1) Except possibly for frequencies in the band of 4 cph to 30 cph the translational mooring motion was about 2 orders of magnitude less than the observed currents and thus is not an important effect;

(2) The torsional motion is important, particularly when considering shear measurements;

(3) The vertical mooring motion may be quite important, particularly in contamination of high frequency signals due to sharp gradients which would give rise to a spectrum having a f^{-2} power law;

(4) Acoustic tracking, particularly pulse and Doppler methods, when used in conjunction with temperature-pressure recorders, can supply an accurate means of assessing the translational motion of a mooring;

(5) High-frequency observations of the angular position of the current meters are required to correct for horizontal response errors in the meters;

(6) Better swivels are required to eliminate the stick slip friction effect which may have caused large angular changes that are difficult to correct for even

when the angular position of the current meters are known. For further detail see Saunders and Green, 1981, and Saunders et al., 1980.

THE MOORING DYNAMICS EXPERIMENT

The Mooring Dynamics experiment took place during 22 days in October 1976. A good overview of the study is given in Walden et al. (1977a). The location of the experiment was the U.S. Navy Barking Sands Pacific Missile Range Facility acoustic tracking range off Kauai in the Hawaiian Islands. Six moorings were implanted during the experiment. Auxiliary XBT and dropsonde data were obtained.

The first mooring was a current meter mooring which was designed to provide environmental current background during the entire mooring period. There were two slack moorings implanted for the NOAA Data Buoy Office (NDBO), one tethered spar mooring, one subsurface mooring which was implanted for the Naval Civil Engineering Lab, and a prototype Navy current meter mooring, known as the DOCMS mooring. Robert Walden of Woods Hole Oceanographic Institution was the principal investigator associated with the environmental mooring and the DOCMS mooring. Three reports resulted from this study to date (Walden et al., 1977; Vachon and Scholten, 1977; Neal et al., 1979.) Chi Associates is preparing a final report of the NDBO moorings. The arrays were tracked by means of acoustic pingers that were placed at several points on the mooring and through the use of hydrophone arrays set out in the Navy's Barking Sands range.

The objective of the study was to obtain data on the forcing (input) fields and the response (outputs) of the six test moorings. These data were then to be used to test and evaluate mooring motion models. Only a cursory comparison with a model was made for the DOCMS mooring; so far no comparisons have been made between the data and models for the other five moorings.

A DISCUSSION OF THE MOORING AND INSTRUMENT COMPARISONS IN MILE AND JASIN

This presentation was primarily a recapitulation of the results published in the Journal of Geophysical Research, Vol. 86, No. C1, January 20, 1981, p. 419-428 by Halpern, Weller, Briscoe, Davis, and McCullough. As this presentation has appeared in the open literature, a copy of the abstract is presented:

> During the August-September 1977 Mixed Layer Experiment (MILE) and the July-September 1978 Joint Air-Sea Interaction (JASIN) project, moored current measurements were made in the upper ocean with Savonius rotor and vane vector-averaging current meters (VACM), dual orthogonal acoustic travel-time vector-averaging current meters (ACM). Wind speeds and significant wave heights reached 20 m s^{-1} and 5 m. The influence of mooring motion upon ACM, VACM, and VMCM measurements are described. In the mixed layer above about 30 m depth where mean currents are relatively large, the effect of a surface-following buoy upon ACM, VACM, and VMCM velocity fluctuations at frequencies less than 0.3 cph was negligible; at frequencies above 4 cph, the VACM data contained the largest amount of mooring induced contamination. Below the mixed layer at depths greater than about 75 m, a subsurface mooring should be used; however, when a surface-following buoy was used, then VMCM data better approximated the spectrum of the fluctuations than VACM data. A A spar-buoy should not be used to measure currents at depths as deep as 80 m. The frequency-dependent differences between VACM and VMCM and between VACM and ACM measurements are described. At frequencies less than 0.3 cph, the differences between the VACM and ACM or the VMCM records were not significant

with 95% confidence limits, were always positive, and above 80 m depth were than 20%. At frequencies above 4 cph, the VACM-VMCM differences were about 5 times larger than the VACM-ACM differences.*

TECHNIQUES FOR MAKING ROUTINE CURRENT SURVEYS IN SHALLOW WATER

A presentation was made of techniques used by the NOAA National Ocean Survey (NOS) in making routine current measurements in estuaries and near-shore coastal waters of the United States. Two types of current meters are regularly used by the NOS. On the east coast the instrumental choice is the Grundy (previously Plessey) current meter, while on the west coast the Aanderaa current meter is the choice. The Grundy current meter uses a Roberts type screw propeller and is mounted in a universal joint type mooring. Direction is obtained by pointing the entire current meter into the flow by means of a cruciform vane. The Aanderaa current meter is a rotor-type instrument. Direction is also obtained by pointing the instrument into the flow by means of a large vane and universal joint type mounting. The moorings are generally shallow in the range of 10-30 meters depth. Occasionally, such as in the Cook Inlet, they may be in water 200 or 300 meters deep. The moorings are generally subsurface type moorings with a surface marker buoy attached. Occasionally a ground line is connected to a secondary recovery float, or a bottom platform with a current meter attached. NOS typically chooses to implant these moorings in regimes (mainly estuaries) where the wave action is expected to be small compared to that of the current, because the current meters respond rather badly under signal-to-noise regimes of less than one.

It was the general consensus of workshop participants that this mooring design is ill-suited for the types of current measurements required. The same conclusion was also expressed regarding the type of current meter. The primary contribution from this presentation appeared to be the implementation of a plan to attempt to certify the current measurements made by NOS. This certification procedure involves precalibration of the current meters, careful recordkeeping of the history of the current meters, and a post-calibration of the current meters with appropriate data processing and correction as required.

VIEWPOINTS FROM THE USERS OF EXISTING TECHNOLOGY

There were two short presentations on existing mooring and current meter technology for the purposes of routine measurement and oceanographic research. There was general dissatisfaction with the lack of support for measuring mooring performance during routine deployments, considering the cost and effort required to mount any kind of mooring project. It appeared that the extra expense involved in assuring the data quality due to mooring motion effects would be small in relation to the total overall cost. Generally, the participants agreed that research and routine moorings should be equipped with pressure sensors and inclinometers when possible.

MOORING MOTION MODELS

A short summary of the history of mooring models was given. Mooring motion models fall into two broad categories: static and dynamic. These can be further divided: one-dimensional, two-dimensional, and three-dimensional models and whether or not the mooring is a single-point or multi-leg type mooring. The mooring motion models for single-point moorings began to proliferate in the late 1960s. This trend continued through the 1970s. The first type of mooring motion model was for single-

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single-point moorings. These were later extended to multiple-leg moorings. Several participants expressed the view that most models for static response of moorings were approximately equivalent. The major drawback to the mooring motion models is that only one or two have been verified with measurements. The dynamical range of currents was small in both cases, so the question of general applicability is still unanswered.

REDUCTION OF MOORING MOTION BY MECHANICAL DESIGN

The total amount of motion experienced by a mooring may be significantly reduced by using a multi-leg configuration. This physically constrains the vertical and horizontal motions of the mooring. The drawbacks of multi-leg moorings are that they are typically extremely difficult and expensive to implant.

High-frequency strumming is an unknown source of drag that could be important in high current situations. The primary method for reducing high frequency strumming motion (which may effectively increase the wire drag coefficient) is attaching fairing to the cables and streamlining the components of the mooring. If the fairings are not rigid (hair fairings or various types of "fur" fairings, for example), the strumming will be reduced but at the expense of increased drag. In order to reduce the drag on the mooring, the fairings have to be rigid.

Several types of rigid fairings that can be attached to a cable were mentioned, and it was suggested that cables with fairings molded on them might be obtained from wire rope manufacturers; this could significantly improve the drag response of mooring cables. It was also noted that the drag response could also be improved by employing smaller diameter cables of higher tensile strength, such as Kevlar. The use of newer engineering materials produced during the space program might offer another avenue of approach; for example, some high purity alloys have very high tensile strength.

CURRENT METER RESPONSE TESTING

For several years now, it has been recognized that the vertical response characteristics of current meters in wave zones may significantly bias the value of the observed current over the averaging period. A similar problem arises from the deviation of the horizontal response of the meters from a cosine law. Several organizations have been involved in measuring the current meter response, both statically and dynamically, and applying the static results to various types of dynamic models. The leader in current meter response measurement is NOAA's Ocean Technology and Engineering Services office. In 1975-1977, Kalvaitis developed the vertical planar motion machine. This has been mounted on tow carriage No. 1 of the David Taylor Naval Ship R&D Center. Both static and dynamic response data may be collected on this facility.

Static vertical response data for a number of different types of current meters, but particularly the Grundy current meter and the Neil Brown acoustic current meter have been collected by NOAA, EG&G, and NORDA. Recently, Appel et al. (1981) described the observations of the vertical response of the Neil Brown current meter and the application of this vertical response to a mooring motion model of the type initially developed by James McCullough (McCullough, 1978; McCullough and Graeper, 1979) and the comparison of this model with the kinematic data obtained on the vertical planar motion mechanism. In general, the comparisons between the model data and the observed data have been very good; the major discrepancy occurs when the instrument passes through its own wake. At that point, the model breaks down as it does not incorporate dynamic effects of wakes.

If the signal-to-noise ratio is defined as the value of the mean current divided by the amplitude of the orbital speed of the current, then most instruments respond rather poorly when the signal-to-noise ratio is less than 1. Conversely, most instruments perform very well when the signal-to-noise ratio is greater than about 2. As a general rule, the Neil Brown current meter underestimates severely in the signal-to-noise range of 0 to 1. Other current meters, depending on the angle of attack and other factors, either overestimate or underestimate at low signal-to-noise ratios.

An experiment (GASP) was conducted in spring 1980 in the Gulf of Mexico in relatively shallow water, approximately 10 meters deep, to evaluate the response of a number of different types of current meters under conditions of high wave activity (Frey and Appell, 1981). It was found that even in such a harsh environment, only approximately 4% of the time were the signal-to-noise conditions less than 1. These results were obtained by using Neil Brown Instrument Systems acoustic current meters operated in a burst mode. The burst mode used was a sampling of 1 measurement every second for 1 minute after which the machine was turned off for an hour. Thus, the signal-to-noise characteristics of the environment were monitored during the entire period of the experiment while not exceeding the data recording capacity of the instrument.

THE NORDA/NBIS CURRENT/CTD PROFILER

Although the NORDA profiler is not a moored instrument, it was thought beneficial to discuss techniques used in removing ship-induced motion from the current data. The NORDA profiler is a three-axis current meter constructed in conjunction with a CTD system (Perkins et al., 1980). It has, in addition, a three-axis accelerometer and a three-axis magnetometer. The instrument is deployed from and tethered to a ship by means of an electromechanical cable. The data are transmitted up the cable in FSK code at the rate of 15 data samples per second. Accelerometer and magnetometer data are used to determine the orientation of the instrument and to provide necessary information for correcting ship-induced motion. At present, the coordinate transformations are based on the assumption that the accelerations are parallel to the gravity vector. Once the direction of the acceleration vector and that of the gravity vector in instrument coordinates are known, the absolute orientation of the instrument is uniquely determined. A first attempt at removal of the vertical motion of the instrument is documented in Saunders et al. (1981).

A more sophisticated system for determining the orientation of the instrument utilizes the known angle of the magnetic dip. The instrument is towed in an east-west direction and the further assumption is made that lateral accelerations are minimal. A more accurate determination of the orientation of the profiler may then be obtained. The reasonableness of assumption on lateral accelerations arises from spectral measurements of all three components of accleration during the initial sea trials of the instrument.

NONLINEAR DOPPLER CONTAMINATION

The problem of nonlinear Doppler contamination of current measurements and/or temperature measurements due to mooring motion interacting with the advected background field was discussed in von Zweck and Saunders (1980). Further work on this problem was presented. As in von Zweck and Saunders, the problem was analyzed by using a spectral approach. An approximation to the Garrett-Munk background spectrum was used with the condition that the spectrum was separable in frequency and horizontal wavenumber. The results of simple numerical experiments were analyzed for the case of an isotropic background. For this case, little effect of nonlinear Doppler contamination was detected. In the case of a unidirectional field there was a possibility of spectral flattening and a proliferation of spurious tidal peaks at all the higher harmonics of the tide. In the open ocean case, where an isotropic background field is to be expected or the locus of the mooring approximates that of a circle, the error is negligible.

III. SUMMARY OF PROBLEM AREAS

From the presentations and discussions it appears there are basically four problem areas relating to mooring motion:

(1) mooring dynamics and characterization;
(2) instrument response and interaction with the mooring motion;
(3) mooring motion reduction;
(4) signal-to-noise improvement.

Each will be discussed in turn.

MOORING DYNAMICS AND CHARACTERIZATION

As far as is commonly known, only two experiments have been designed specifically to measure and characterize the motion of single point moorings. These were the Mooring Dynamics Experiment at Kauai and the ATOM '79 Experiment in the Gulf of Mexico. The major drawback of these two experiments was that neither included taut surface moorings designed for measuring the currents and other physical background near the surface. But both provided data that can be used as inputs to numerical models of moorings and to compare those models with the observed motions. A number of models exist, but there are few models which have been tested and evaluated against actual observed mooring motion data.

A great deal of information could be obtained on all standard moorings by providing in line instrumentation to measure inclination and direction of the mooring line, the tension of the mooring line, and the depth at a number of points along the line. This would be simple to implement and would not involve the expense of including acoustic tracking instrumentation deployed in the vicinity of the mooring and on the mooring line itself. The relative cost to implement this feature on all routine moorings would be small in proportion to the basic cost of the mooring.

INSTRUMENT RESPONSE/INTERACTION WITH MOORING MOTION

The initial results of Gould and Sambuco (1975) and Gould et al. (1974) indicated, at least for deeper current meter measurements, that taut surface moorings appeared to introduce a significantly greater amount of contamination than subsurface moorings. The apparent cause of this contamination was the vertical motion of the current meter interacting with its poor vertical cosine response. Results of static calibrations and comparisons with dynamic response models have shown that for signal-to-noise ratios of less than about 1, the errors induced by the non-cosine response in the vertical may be quite significant for current meters such as the Neil Brown acoustic current meter, the VACM, the Aanderaa, and the Grundy (or Plessey) current meter.

The results of the JASIN and MILE experiments showed that taut moorings can be used with little error, provided the current meters are placed no more than about 50 m below the surface. In the ATOM '79 mooring, the horizontal response, coupled with torsional motion appeared to be the cause of the greatest amount of error in the current measurements. Careful measurements of the vertical cosine response, when incorporated into the appropriate type of model, have shown good agreement with dynamic measurements made on the Vertical Planar Motion Mechanism at the David Taylor Model Basin (DTNSRDC). These experiments have shown the utility of such models for predicting the dynamic response under a number of different wave and current conditions, and provide a useful tool for estimating the upper bound of the error involved. The GASP experiment (Frey and Appell, 1981) has provided a useful application of burst sampling in order to estimate the signal-to-noise ratio as a function of time during a mooring experiment, thus allowing a time dependent error bound to be placed on this type of contamination.

MOORING MOTION REDUCTION

There are two basic causes for mooring motion which affect measurements f physical oceanographic parameters in the upper ocean. The first is the respons the mooring to horizontal currents. The second is the response of the buoy to forces. In the first case, drag is the principal force involved. In the sec the principal force involved is the buoyancy. Therefore, mooring motion may reduced by first reducing the drag of the mooring. This may be done by fairin streamlining the cable and other elements of the mooring, or by making the diameter of the cable smaller.

For fairing to reduce the drag, the fairing has to be rigid, streamlined, and not large in frontal area. This would indicate that the fairing should be either a rigid material applied to the cable after manufacture or molded directly to the cable. If it is molded directly to the cable, better swivels must be designed to connect various short lengths of cable. The reduction of the diameter of the cable may be implemented by the use of new high tensile strength materials which have been developed in recent years.

The effects of drag may be countered, but not reduced, by the use of multi-leg moorings. Even though the drag forces are not reduced, the use of multi-leg moorings introduces physical kinematic constraints to the moorings. They are, however, difficult to deploy and are much more costly than single point moorings. The reduction of mooring motion due to surface wave action may be implemented by compliant buoy design. This includes the use of spar buoys and, in particular, spar buoys whose buoyancy increase with increasing draft.

SIGNAL/NOISE IMPROVEMENT

The signal-to-noise ratio may be improved by implementing "smart" instruments, an example being an instrument that incorporates the vertical or horizontal response along with a dynamic motion model similar to that developed by McCullough. This model would be employed in real time to correct as much of the signal as possible during data acquisition. The major problem involved with this type of processing is one of battery life as the microprocessors presently used have higher consumption than can be supplied within the small battery compartments. An alternate approach to this is to use burst sampling or compressed data storage techniques. At present, there are few current meters being regularly deployed which sample in a burst mode. Also, the use of multiple recording devices within the current meter are certainly possible, but few current meters are implementing these methods. Possibly the use of magnetic bubble technology may offer hope for compressed data storage. The use of multiple signal and advanced filtering methods may offer another approach to the improvement of signal-to-noise problems.

The second obvious area in signal-to-noise improvement is that of improving the mechanical design of the instruments to reduce their non-cosine response characteristics. The Davis-Weller current meter is a particularly good example of a meter specifically designed to possess good cosine response characteristics. It may well be that a current meter of this type will be the instrument of choice to be used for upper ocean measurements. Any judgment of this instrument should be made after definitive tests have been made using the Vertical Planar Motion Mechanism, after careful response studies have been made of its vertical and horizontal cosine responses. Other instruments which show great promise in the area of their response characteristics are electromagnetic current meter and acoustic Doppler backscatter methods such as those used by Pinkell, and some methods which have been proposed for short scale acoustic backscattering in small current meters which have not yet been implemented. The reduction of the sensor size in order to reduce the self-interference of the meters with the flow being measured has also been suggested.

Because of the great cost of existing current meters and the extraordinary expense involved in replacement with better designed meters, the possibility of retrofitting these current meters to improve response characteristics should be carefully investigated. For example, a simple retrofit of the Neil Brown current meter might involve simply putting a large vane on the current meter and orienting the sensors into the flow. Whether or not this would work in a wave zone is unknown, but in a region below the wave zone or on a mooring, such as a subsurface mooring, this might reduce the effects of the non-cosine horizontal response when coupled with the torsional motion. Finally, the use of improved array designs, such as floating or drifting arrays, either rigid or flexible, and the use of differential measurements which would increase the common mode rejection of mooring motion should be seriously considered.

IV. RECOMMENDATIONS

At the workshop's conclusion, the participants drafted a series of recommendations. These findings do not necessarily represent the group as a whole, as many were required to depart early. These recommendations follow:

(1) Initiate a five-year effort to produce a sensor capable of 1 mm/sec accuracy in currents.

(2) In coordination with (1), develop a floating platform that is as free as possible of wave interference and drag.

(3) Evaluate a suite of mooring motion models using real mooring motion data. This may be termed an "olympiad" of mooring motion models.

(4) Initiate a program to improve mooring line characteristics, for example, tensile strengths and fairing.

(5) Suggest routine monitoring of pressure, tangent vector, and rotation of the mooring line at several points on all future Navy-funded moorings.

(6) Evaluate the use of drifting arrays for high frequency, high wavenumber monitoring in the upper ocean.

(7) Use differential measurements where possible to eliminate common mode problems.

(8) Fund development of smart instruments and direct monitoring of in situ density.

APPENDIX A

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APPENDIX B

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This report is a summary of presentations and discussions related to mooring motion problems. The workshop was conducted July 28-30, 1981. Each participant was invited on the basis of his or her expertise in mooring motion and/or upper ocean measurement. Mooring motion, as it applies to upper ocean measurement, is a highly specialized field but may be further subdivided. As each participant had interests in one or more of those subdivisions, it was natural that their presentations should reflect those interests. On the other hand, it was the responsibility of the conveners of this workshop to present the results in a

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